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ORE MICROSCOPY AS A GUIDE TO ORE DRESSING PROCEDURE

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1. Definition of Ore Microscopy

Since its first modern application more than fifty years ago[1], ore microscopy has become not only an important branch of mineralogy, but has also proven itself indispensable in the fields of mining geology, mineral processing and extractive metallurgy. In a strict sense, the term "ore microscopy" refers only to the examination of opaque minerals in polished sections under the reflecting microscope. In modern practice, however, it implies much more. Now the importance of the transparent gangue minerals in metallic ores is recognized, and the growing significance of such elements as niobium and beryllium requires that the transparent minerals in which they occur be studied in detail. Then too, we are faced with diminishing mineral resources and consequently with the necessity of exploiting deposits that are mineralogically complex and hence difficult to treat. This has resulted in the use of several other techniques supplementing the microscope. For instance, X-ray powder diffraction methods are used for the identification of the minerals and the recently developed electron probe micro-analyser is most helpful in determining the distribution of the elements among the mineral grains. However, in spite of these modern trends, the microscope itself remains the most useful basic means of learning the character of mineral assemblages. In this very brief summary of its use in the field of ore dressing, the strict meaning of the term "ore microscopy" will be adhered to closely.

2. Apparatus

(a) General statement: The apparatus required for ore microscopy will vary widely in complexity and cost, according to the need and the funds available. The references include many excellent descriptions of the apparatus and its uses. In general it is true that a minimum of apparatus essential for the microscopical examination of metallic ores will yield the greatest return on the investment, and that elegant and costly accessories should be avoided unless they are needed for special cases.

(b) Polishing apparatus: The preparation of polished sections may be either a simple or a complicated procedure. Solid sections of ores can be prepared very simply by hand-polishing the unmounted specimens on relatively inexpensive machines[2, 3]. Fragmented samples, such as mill products, require mounting before polishing, and since their study cannot be avoided in connection with ore dressing, a means of mounting must be provided. Some ores are soft and friable and their preparation is extremely difficult and involves impregnation with special resins. In fact, the preparation of polished sections is a highly skilled craft and minerals vary so greatly in physical character that it is not surprising that the methods for polishing ores also vary in detail[2, 3, 4, 5, 6]. Basically however, the minimum of equipment required includes a rough grinding lap for shaping ore specimens, facilities for mounting ores and mill products in plastic[7, 8], and polishing machines fitted with either metal or fabric-covered laps[2, 3, 4, 5]. More elaborate installations would include a precision diamond saw, semi-automatic polishing machines and many other accessory devices.

(c) Microscopical apparatus: The most important requirement for ore microscopy is a modern reflecting microscope of highest quality. Accessories can be added as required. A microscope that can be converted to a petrographic microscope by using an additional tube and sub-stage is highly desirable. There should be at least three air objectives for low, medium and moderately high powers of magnification, and a good high power oil immersion objective. Many additional accessories may be required for special purposes such as photomicrography, statistical grain analysis and measurement of reflectivity, but a good microscope equipped with objectives covering a wide range of magnifications and having a micrometer ocular and traversing stage for grain analyses, will be found to be adequate for many purposes.

3. The Microscopical Examination of Polished Sections

(a) General statement: The microscopical examination of polished sections of ores and mill products must be done by trained personnel. It will be apparent, after referring to any of the standard works on the subject, that especially the interpretation of mineral textures and their correlation in terms of milling behavior require training and experience.

(b) Identification of minerals: The identification of the minerals in polished sections under the reflecting microscope is based upon their optical, physical and chemical properties[4, 9, 10, 11, 12, 13]. Optical properties include colour, brightness (reflectivity), anisotropic effect and the character of any internal reflections. Physical properties are hardness, sectility, crystal habit, cleavage or parting, and zoning as reflected in systematic fracturing and pitting. Chemical properties that can be observed under the microscope are normally restricted to surface reactions brought about through the application of etching reagents[12]; this also tends to display any zoning due to changes in chemical composition. Microchemical tests[12] are sometimes very useful and although most of the common minerals can be recognized readily in polished

sections after some experience, positive identification of minerals in complex and fine-textured ores is frequently difficult. If such ores are encountered, it may be necessary to employ some of the supplementary techniques mentioned earlier in paragraph 1, for the identification and characterization of the minerals.

(c) Form and texture: The form and texture shown by minerals and the manner of their mutual association[4, 14, 15, 16] are the basic guides to ore dressing procedure. The minerals are the units, and the ore dressing engineer has to separate the valuable constituents from those that are worthless. Therefore, their grain sizes, physical characteristics and the degree to which they are combined with one another will determine the extent to which grinding must be carried to effect their separation.

(d) The examination of mill products: The examination of mill products in conjunction with ore dressing procedures, either in testing laboratories or in operating mills, is indispensable, particularly when difficulties arise in separating the minerals. When the significant products are studied microscopically, the cause of the trouble is usually quite apparent. It is advisable to study the solid ore sections before the examination of mill products is attempted, because the minerals can be more easily identified in the larger grains of the solid ore than in the smaller fragments. In fact the study of ore prior to its test treatment can frequently save the engineer many hours of testing, and in some instances the behavior of the ore can be forecast with remarkable accuracy. In operating mills it is advisable to use a binocular microscope, because the experienced engineer can tell a great deal about the functioning of the circuits by examining the products.

(e) Grain analyses: Grain analyses can be very useful in ore dressing operations. Several methods have been used for ascertaining the relative quantities of the minerals in ores and mill products[2, 4, 17]. Sometimes very complete statistical studies have been made to determine the degrees of freedom and the combinations of the various minerals of a complex ore. Such studies, however, are ordinarily too fatiguing and time-consuming to be justified, and some thought is now being given to find a method of performing these analyses automatically through the use of modern electronics applied to the varying reflecting characteristics of the ore minerals.

4. Interpretation of Microscopical Data

(a) Gold ores: The interpretation of microscopic features in terms of ore dressing procedures is based on their correlation with the behavior of the ore under milling conditions. The relationship between mill practice and the manner in which gold occurs illustrates this rather clearly. If the gold occurs as comparatively coarse grains and veinlets in quartz (See Fig. I) or in sulphides (See Fig. II), satisfactory recoveries can be expected to result from comparatively coarse grinding and gravity methods of separation. If its average grain size is less (See Fig. III), the ore may require finer grinding followed by cyanidation to recover the finer gold. If sulphides are present, as they frequently are in the form of pyrite and arsenopyrite, some of the gold may be enclosed within the sulphides (See Fig. IV). If the inclusions are in

very dense sulphide (See Fig. V), the sulphides may have to be concentrated by flotation, re-ground and cyanided. When the average grain size of the gold in the sulphides is very small (See Figs. V and VI), recovery by cyanidation of the flotation concentrate may be negligible; in such cases the concentrates must be roasted before re-grinding and cyanidation. Fig. VI shows tiny gold particles in arsenopyrite; in this ore the arsenopyrite itself is very finely disseminated, and presents a problem in concentration. In fact, for this reason, the operation of the mine was on the economic borderline. It is probable that in some ores the gold is largely in sub-microscopic form, and possibly also in solid solution. The presence of interfering minerals, such as talc or other soft flakey minerals, may cause trouble. Chalcopyrite (See Fig. VII), as well as pyrrhotite, can contaminate cyanide solutions and cause trouble in the circuits. Acute complications are introduced when gold and silver tellurides, graphite, et cetera are present in appreciable quantities as shown in Fig. VIII.

(b) Iron ores: The beneficiation of iron ores requires treatment of very large tonnages by very economical methods. The coarse-textured ore seen in Fig. IX is easily treated by gravity and magnetic separators. On the other hand the ore shown in Fig. X is practically impossible to treat economically. A titanium-bearing ore, in which ilmenite, hematite and magnetite occur as separate, individual, relatively coarse grains, can be treated satisfactorily, but no amount of grinding can free the intimately admixed ilmenite-magnetite or ilmenite-hematite intergrowths (See Fig. XI) frequently found in titaniferous iron deposits.

(c) Base metal ores: Base metal ores show great variation in their characteristics and, hence, present a great variety of problems to the ore dressing engineer. Some are coarse textured and the minerals are comparatively easy to separate (See Fig. XIII), while others are fine textured and the minerals are so intimately associated that their separation is impractical, if not impossible (See Figs. XII and XIV). The reason for poor recoveries or incomplete separation of the minerals is usually apparent when the products are examined microscopically. Two examples are given in Figures XV and XVI, but numerous others have been recorded.

5. Conclusion

It must be remembered that metallic ores seldom even approach homogeneity in the distribution of the minerals. In fact ores commonly show very wide variations throughout a deposit, and each type presents a unique set of problems that must be solved before it can be treated satisfactorily. Ore microscopy is one of the most effective weapons in solving these problems and for guiding and improving ore dressing practice.

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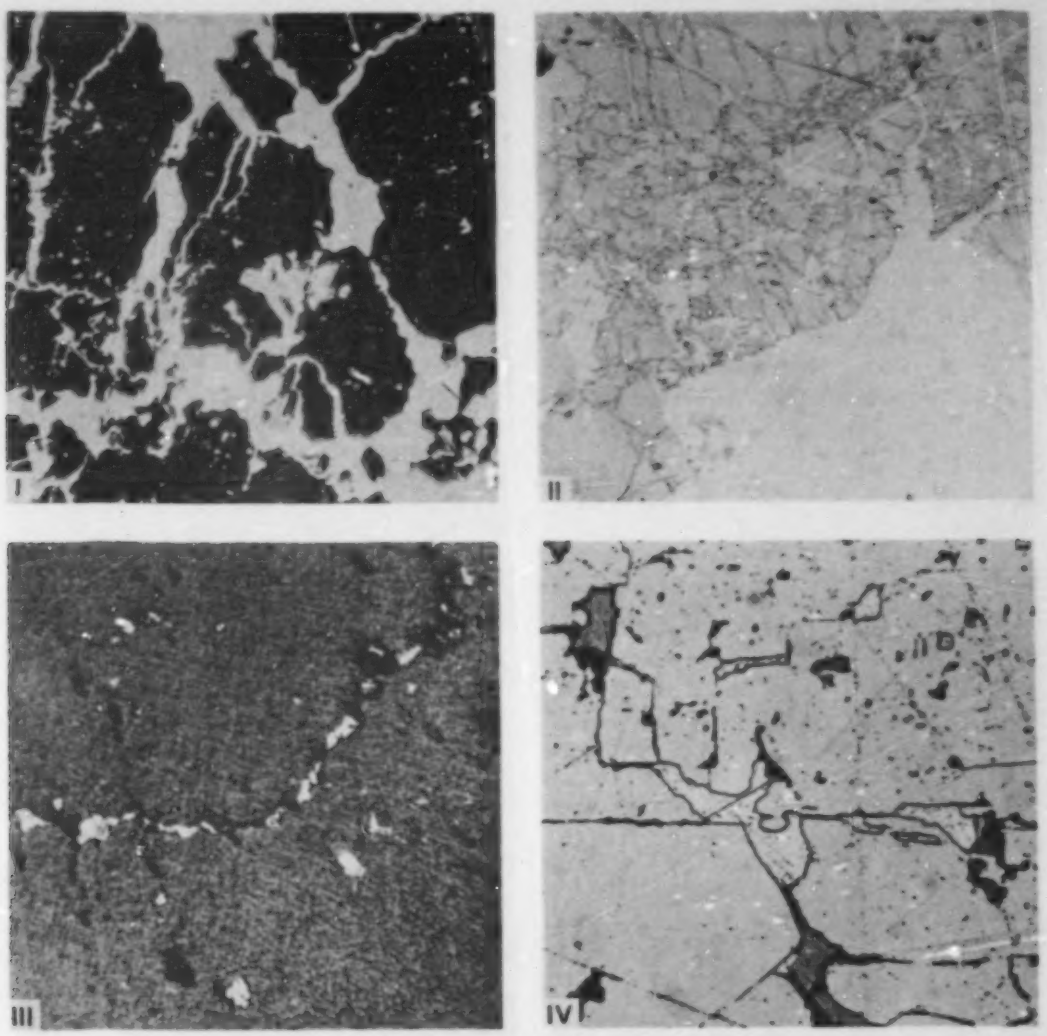


Fig. I Polished section of rich gold ore from Lake Shore Mine, Ontario. The veinlets of gold (white) in the quartz (black) are very easily freed and recovered by gravity methods. Magnification 50x.

Fig. II A very rich section of gold ore from the Bralorne Mine, British Columbia. Here the coarse gold is associated with arsenopyrite (grey). This type of gold occurrence presents no treatment problem. 50x.

Fig. III Gold in quartz from the Porcupine District, Ontario. This gold (white) occurs as much smaller grains, and treatment involves finer grinding and cyanidation. 100x.

Fig. IV Moderately coarse to fine gold (white) in pyrite (light grey) and quartz gangue (dark grey) from northern Ontario. The coarse gold is recovered by gravity methods, the finer must be recovered by cyanidation. 100x.

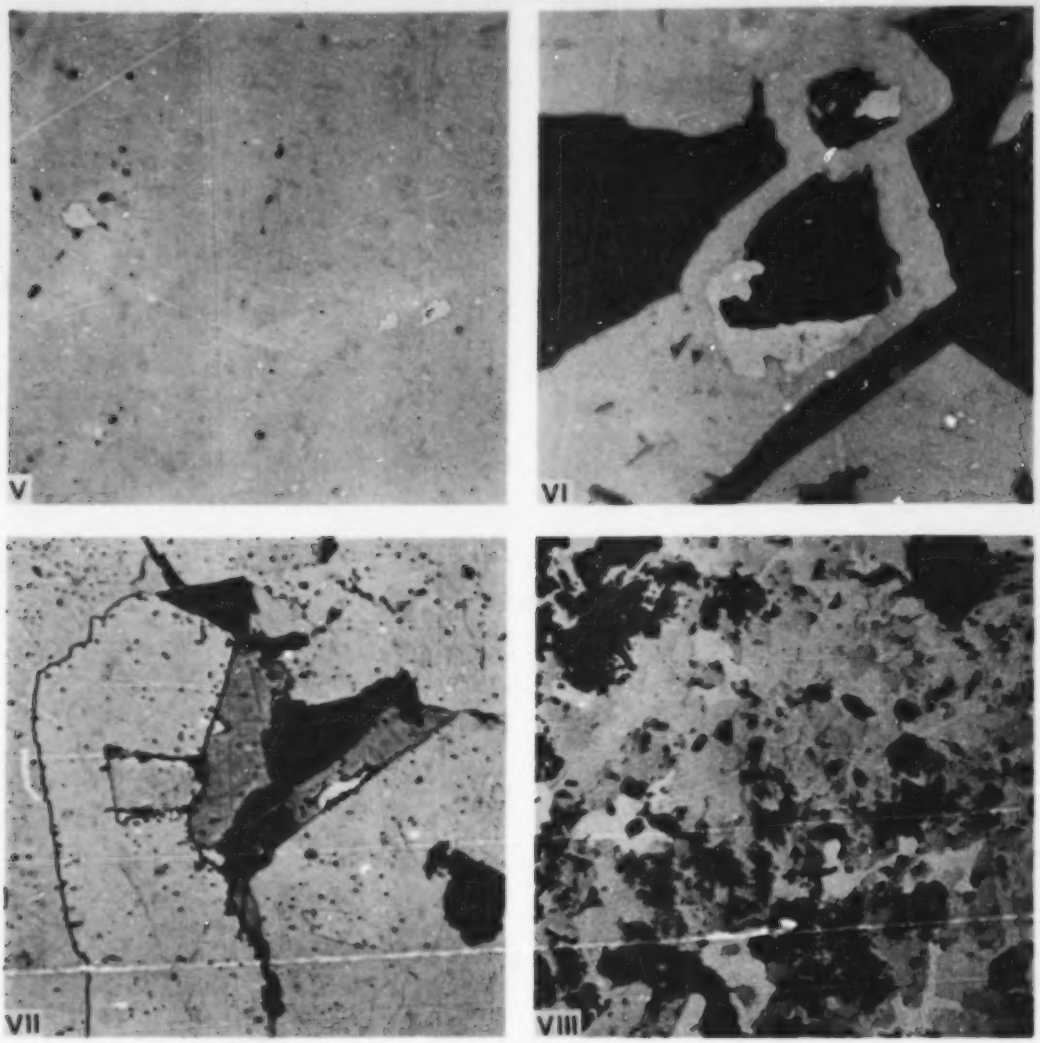
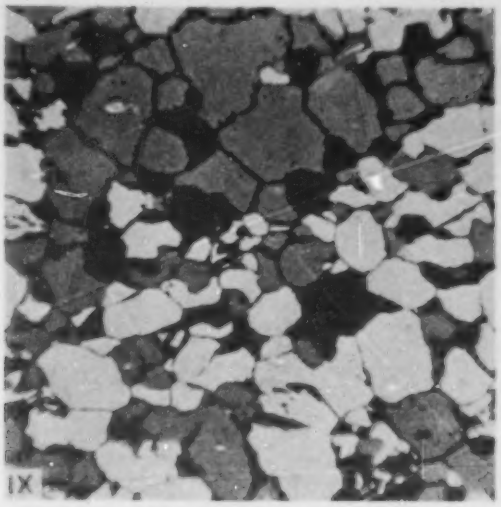


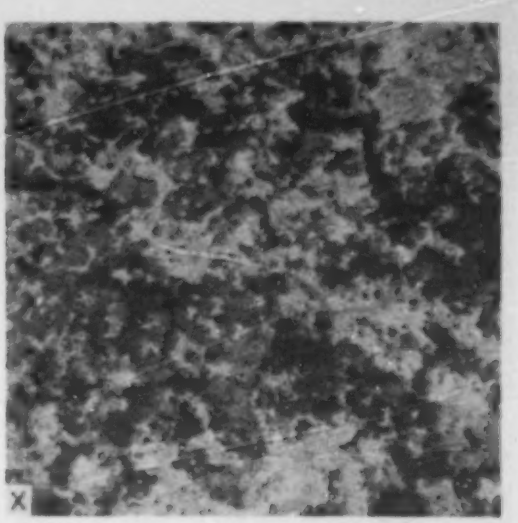
Fig. v Tiny grains of gold (white) in dense pyrite (grey) from northern Ontario. The sulphides are concentrated by flotation and cyanided after re-grinding. 1000x.

Fig. VI Tiny grains of gold (white) in skeletal crystals of arsenopyrite from Beattie Gold Mine, Quebec. The arsenopyrite must be concentrated and the concentrate roasted and re-ground before cyanidation. 1500x.

Fig. VII Tiny grains of gold (white) along the boundaries of chalcopyrite (dark grey), pyrite (light grey) and arsenopyrite (slightly darker grey than the pyrite). The black areas are pits. 1000x.

Fig. VIII A rich section of gold from Kirkland Lake, Ontario. Here the gold occurs with an assemblage of gold and silver tellurides, pyrite (varying shades of grey), graphite (not shown in this field) and quartz (black). This requires complex treatment. 500x.





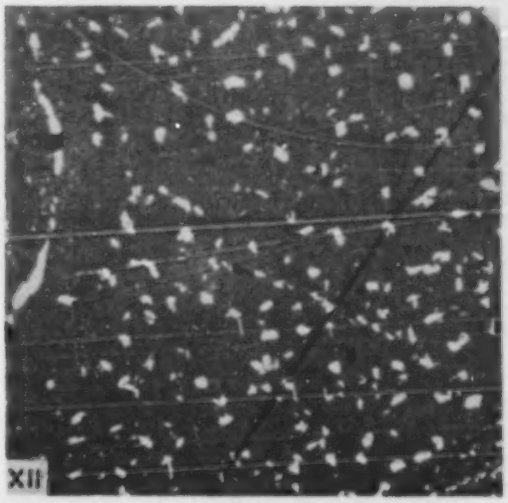
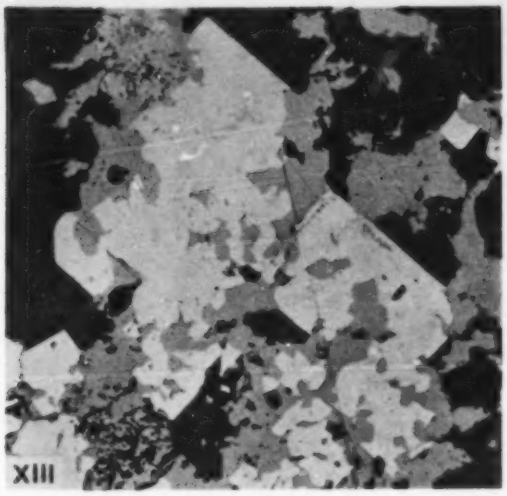


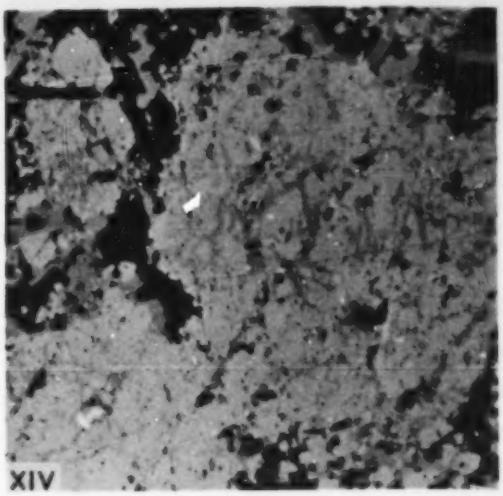
Fig. IX Iron ore from central Labrador, Newfoundland. Coarse magnetite and hematite (both white) in quartz, and carbonate gangue (grey). Pits are black. The iron minerals are freed from the gangue minerals very easily. 100x.

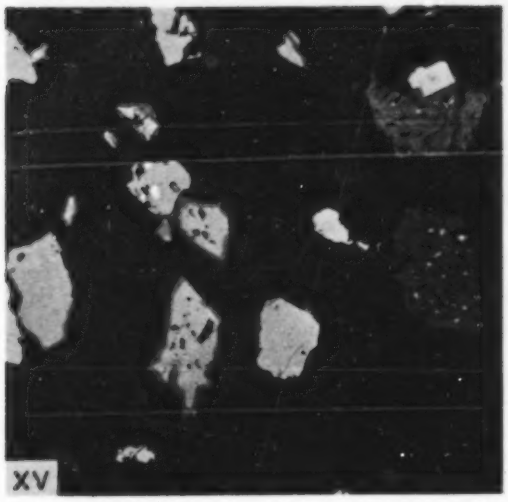
Fig. X Heavily oxidized iron ore from central Labrador, Newfoundland. The ore is soft and friable, and the minerals include goethite, hematite and silicates. Beneficiation is very difficult, if not indeed impossible by gravity methods. 1000 x.

Fig. XI Hematite-ilmenite intergrowth in an iron ore from Ontario. The hematite is white, the magnetite is grey. These cannot be separated mechanically. 1000x.

Fig. XII Numerous tiny exsolved inclusions of chalcopyrite (white) in sphalerite (grey) in a base metal ore from New Brunswick. It is obvious that the copper and zinc of this assemblage cannot be separated mechanically. 1600x.







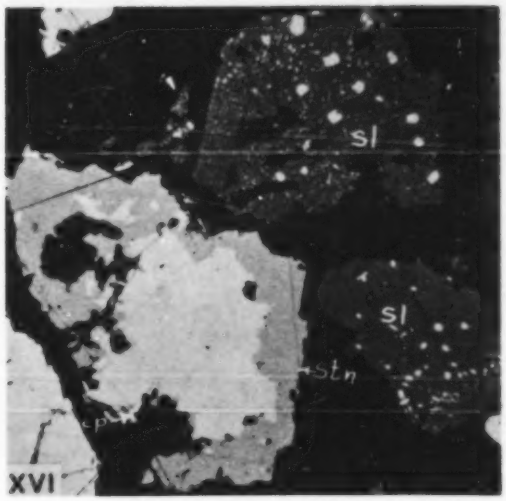


Fig. XIII Coarse-textured intergrowth of sphalerite (light grey) and pyrite (white, with cubic habit) in quartz (dark grey) from British Columbia. 50x.

Fig. XIV Pyrite (white) intricately veined by chalcopyrite (light grey) and associated with sphalerite (dark grey) and quartz (black). Copper-zinc ore from northern Quebec. 200x.

Fig. XV Combined grains in a flotation concentrate from a British Columbia mill. Chalcopyrite (light grey) rimmed by chalcocite and covellite (grey and indistinguishable from one another in the photomicrograph), and sphalerite (dark grey) containing numerous tiny dots of exsolved chalcopyrite, and in one instance still attached to pyrite (white). The mounting medium is black. 200x.

Fig. XVI Combined grains in a concentrate from a copper-tin ore from New Brunswick. Chalcopyrite (white - cp), stannite (light grey - stn) and sphalerite (dark grey - sl). The mounting medium is black. 1000x.

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